

Laser-Ablated $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3/\text{LaAlO}_3$ Films Analyzed Statistically for Microwave Applications

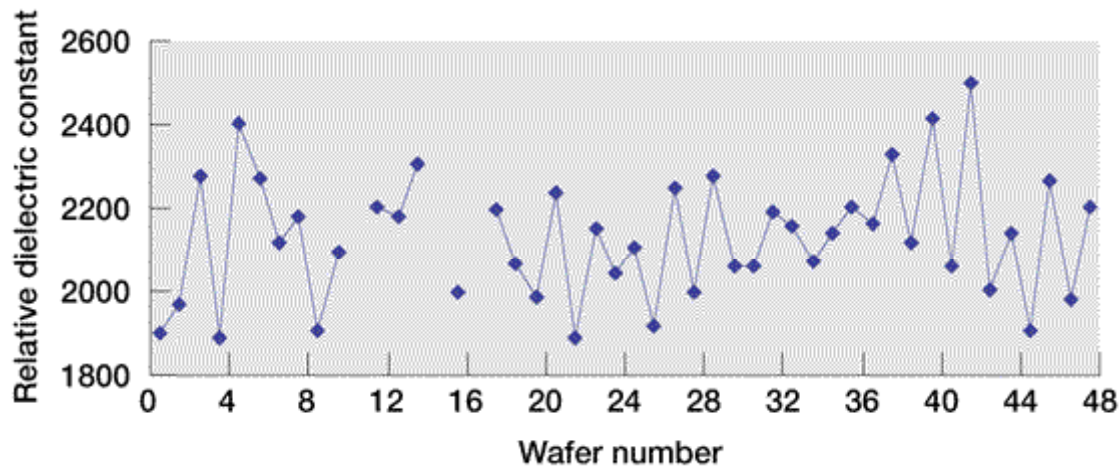
Scanning phased-array antennas represent a highly desirable solution for futuristic near-Earth and deep space communication scenarios requiring vibration-free, rapid beam steering and enhanced reliability. The current state-of-practice in scanning phased arrays is represented by gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) technology or ferrite phase shifters. Cost and weight are significant impediments to space applications. Moreover, conventional manifold-fed arrays suffer from beam-forming loss that places considerable burden on MMIC amplifiers. The inefficiency can result in severe thermal management problems.

The NASA Glenn Research Center is constructing an innovative type of scanning phased-array antenna, using thin-film ferroelectric barium-strontium-titanate- ($\text{Ba}_x\text{Sr}_{1-x}\text{TiO}_3$) based phase shifters, that promises to overcome these disadvantages. A critical milestone is the production of 616 identical 19-GHz phase shifters with an insertion loss of ~ 4 dB, a phase shift of at least 337.5° , and a bandwidth of 3 percent. It is well known that ferroelectric film crystallinity and strain, affected by the substrate template, play an important role. $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3$ films, nominally 400 nm thick, were deposited on forty-eight 0.25-mm-thick, 5-cm-diameter lanthanum-aluminate (LaAlO_3) wafers using pulsed laser deposition (PLD). The composition was selected as a compromise between tuning and loss for room-temperature operation (e.g., crystallinity progressively degrades for Ba concentrations in excess of 30 percent). As a prelude to fabricating the array, it was necessary to process, screen, and inventory a large number of samples. Variable angle ellipsometry was used to characterize the refractive index and film thickness across each wafer. Microstructural properties of the thin films were characterized using high-resolution x-ray diffractometry. Finally, prototype phase shifters and resonators were patterned on each wafer and radiofrequency-probed to measure tuning as a function of direct-current (dc) bias voltage as well as peak (0 field) permittivity and quality factor Q_o . This work presents the first statistically relevant study of film quality and microwave performance and represents a pivotal milestone toward spacecraft utilization of thin ferroelectric films for microwave applications.

For any phased-array antenna to be realized with ferroelectric materials, or any device technology for that matter, the phase shifters must be reproducible in terms of insertion loss and insertion phase shift. For example, random phase errors exceeding 45° can significantly degrade the main beam power. Very good reproducibility was obtained both across the 48 wafers and from wafer to wafer in terms of crystal quality. For wafers 1 to 24, the mean in-plane lattice parameter was 3.9816 \AA ($\sigma = 0.0021$)¹ and the mean out-of-plane lattice parameter was 3.9637 \AA ($\sigma = 0.0012$). For wafers 25 to 48, the mean in-plane lattice parameter was 3.9797 \AA ($\sigma = 0.0016$) and the mean out-of-plane lattice parameter was 3.9643 \AA ($\sigma = 0.0005$). The full-width half-maximum (FWHM) of the

(002) peak was generally better than 0.1° and significantly better than this for the second batch of 24 wafers.

On the basis of the ellipsometric analysis, the means and standard deviations (in parentheses) for the film thicknesses at the center, 12.7-mm off center, and 19.0-mm off center were 3767 Å (340 Å), 3677 Å (313 Å), and 3469 Å (273 Å), respectively. Film thickness plays a crucial role in microwave performance. Despite some variations in thickness and crystallinity, the microwave performance was very consistent. The mean Q_o was 14.1, with a standard deviation of 1.0. The mean insertion phase shift was 20.5° , with a standard deviation of 1.4° . The Q measurements suggest that the film quality, in terms of loss tangent, is very reproducible. The peak dielectric constant of the $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3$ layer for each wafer is shown in the graph. The mean peak dielectric constant was 2129 with a standard deviation of 149.



Peak (0 field) dielectric constant of the $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3$ layer extracted from $\lambda/2$ and λ microstrip resonators.

In summary, the two batches totaling 48 PLD $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3/\text{LaAlO}_3$ wafers are suitable, from a microwave point of view, for fabrication into phase shifters and incorporation into a state-of-the-art phased-array antenna. In the near future, the remaining 46 wafers will be patterned with approximately 30 phase shifters each. Then, the phase shifters will be sampled on-wafer (about 10 percent tested) and inventoried for use in the ferroelectric reflectarray antenna.

Reference

1. Romanofsky, R., et al.: A Statistical Analysis of Laser Ablated $\text{Ba}_{0.50}\text{Sr}_{0.50}\text{TiO}_3/\text{LaAlO}_3$ Films for Microwave Applications. MRS Proceedings, vol. 720, 2002, pp. 111-122.

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¹Standard deviation.